Influence of 3D Cloud Effects on Satellite-Derived Earth Radiation Budget Estimation

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CERES Instrument

- 5 instruments on 3 satellites (TRMM, Terra, Aqua) for diurnal and angular sampling.
- Narrow field-of-view scanning radiometer with nadir footprint size of 10 km (TRMM); 20 km (Terra & Aqua).
- Measures radiances in 0.3-5 μm, 0.3-200 μm and 8-12 μm.
- Capable of scanning in several azimuth plane scan modes: fixed (FAP) or crosstrack, rotating azimuth plane (RAP), programmable (PAP).
- Coincident Cloud and Aerosol Properties from MODIS/VIRS

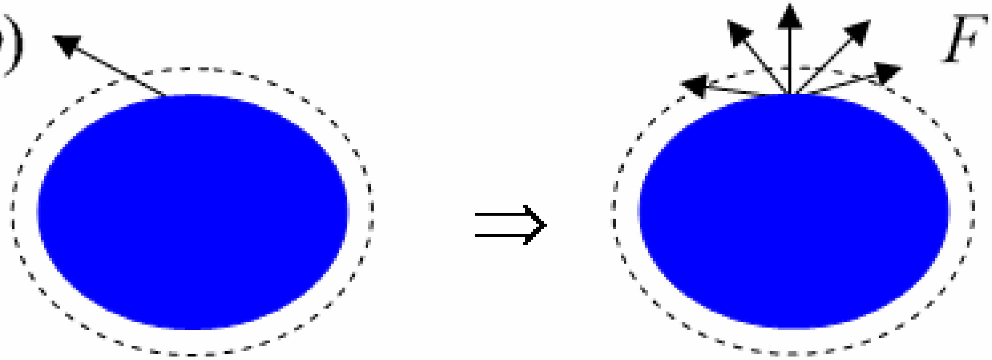
Instantaneous Fluxes at TOA and Angular Distribution Models

CERES Radiance Measurement

$L(\theta_o, \theta, \phi)$

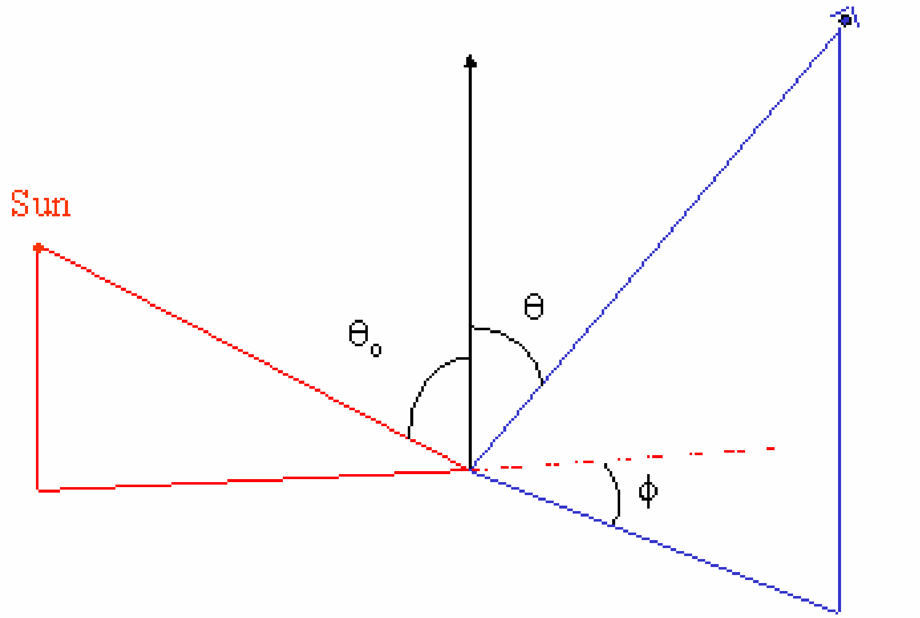
TOA Flux Estimate

$F(\theta_o)$



SW
LW
WN

$$F(\theta_o) = \int_0^{2\pi} \int_0^{\frac{\pi}{2}} L(\theta_o, \theta, \phi) \cos\theta \sin\theta \, d\theta \, d\phi$$



TOA flux estimate from CERES radiance:

$$\hat{F}(\theta_o,\theta,\phi) = \frac{\pi L(\theta_o,\theta,\phi)}{R_j(\theta_o,\theta,\phi)}$$

where,

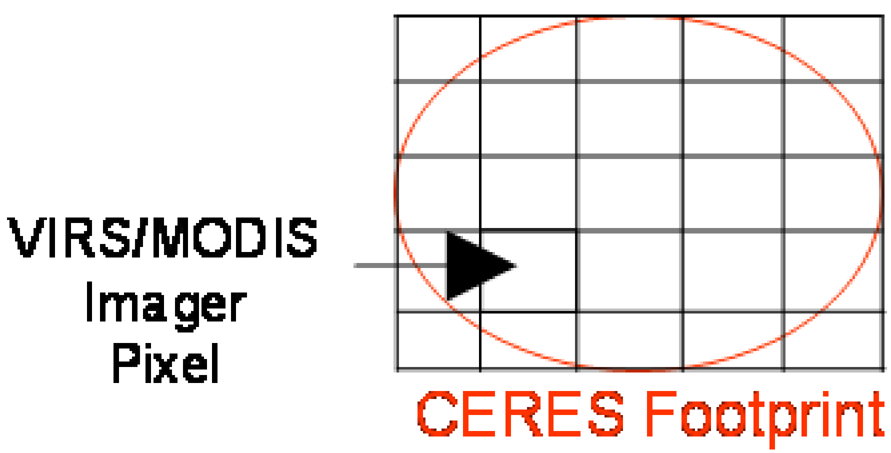
$$R_j(\theta_o,\theta,\phi) = \frac{\pi L_j(\theta_o,\theta,\phi)}{\int_0^{2\pi}\int_0^{\frac{\pi}{2}} L_j(\theta_o,\theta,\phi)\cos\theta\,\sin\theta\,d\theta\,d\phi}$$

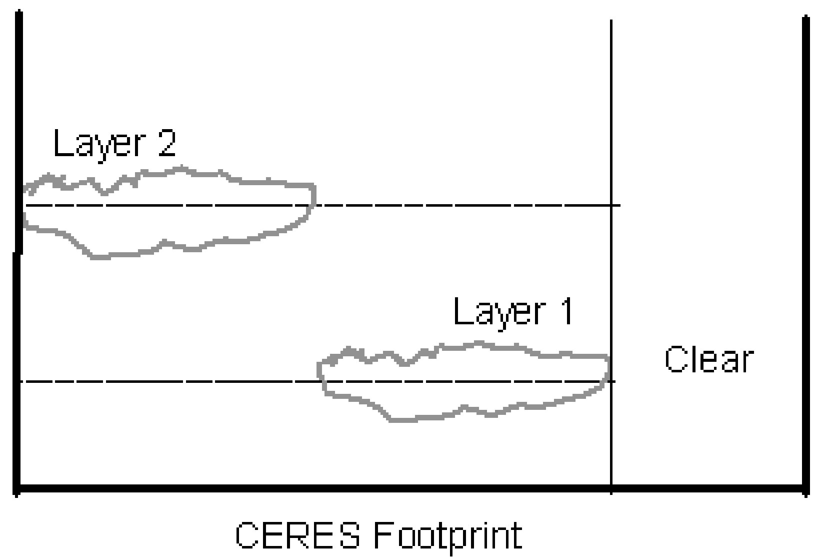
$R_j(\theta_o,\theta,\phi)$ is the Angular Distribution Model (ADM) for the "jth" scene type.

CERES Single Scanner Footprint (SSF) Product

- Coincident CERES radiances and imager-based cloud and aerosol properties (including MOD04 and NOAA-NESDIS aerosol products).
- Use VIRS (TRMM) or MODIS (Terra, Aqua) to determine the following parameters in up to 2 cloud layers over every CERES FOV:

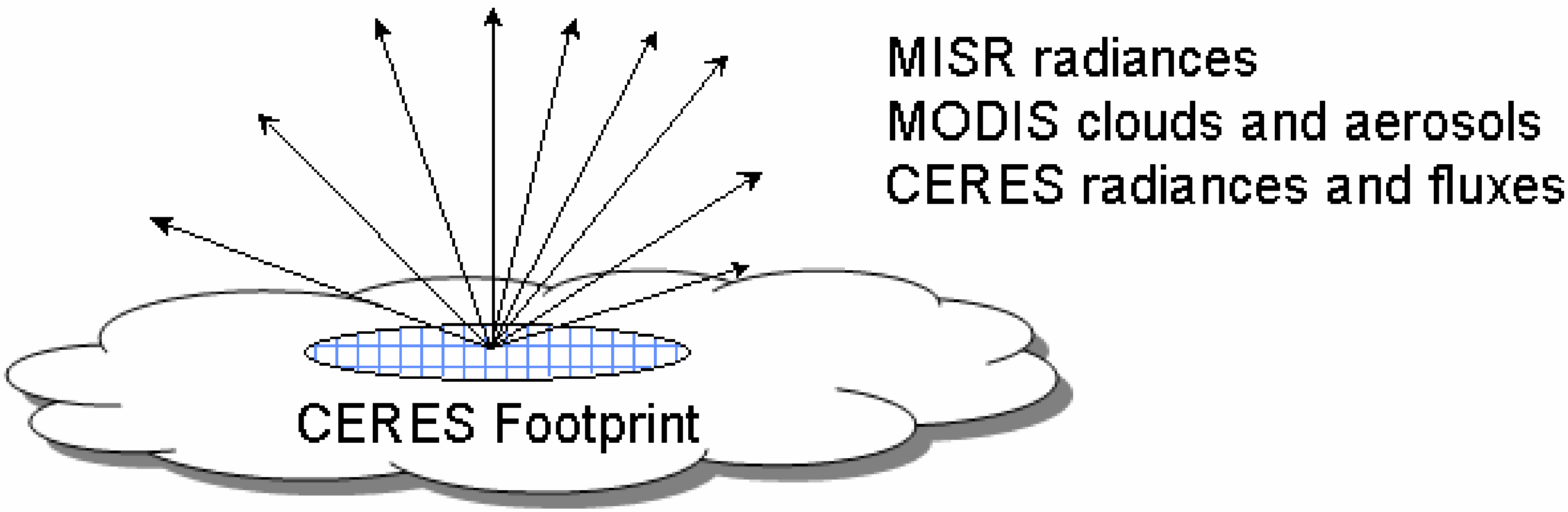
Macrophysical: Fractional coverage, Height, Radiating Temperature, Pressure
Microphysical : Phase, Optical Depth, Particle Size, Water Path
Clear Area : Skin Temperature, Aerosol optical depth, Emissivity





NEW MERGED CERES-MISR-MODIS DATASET

CERES and MISR teams are working together to produce the first merged CERES-MISR-MODIS dataset.



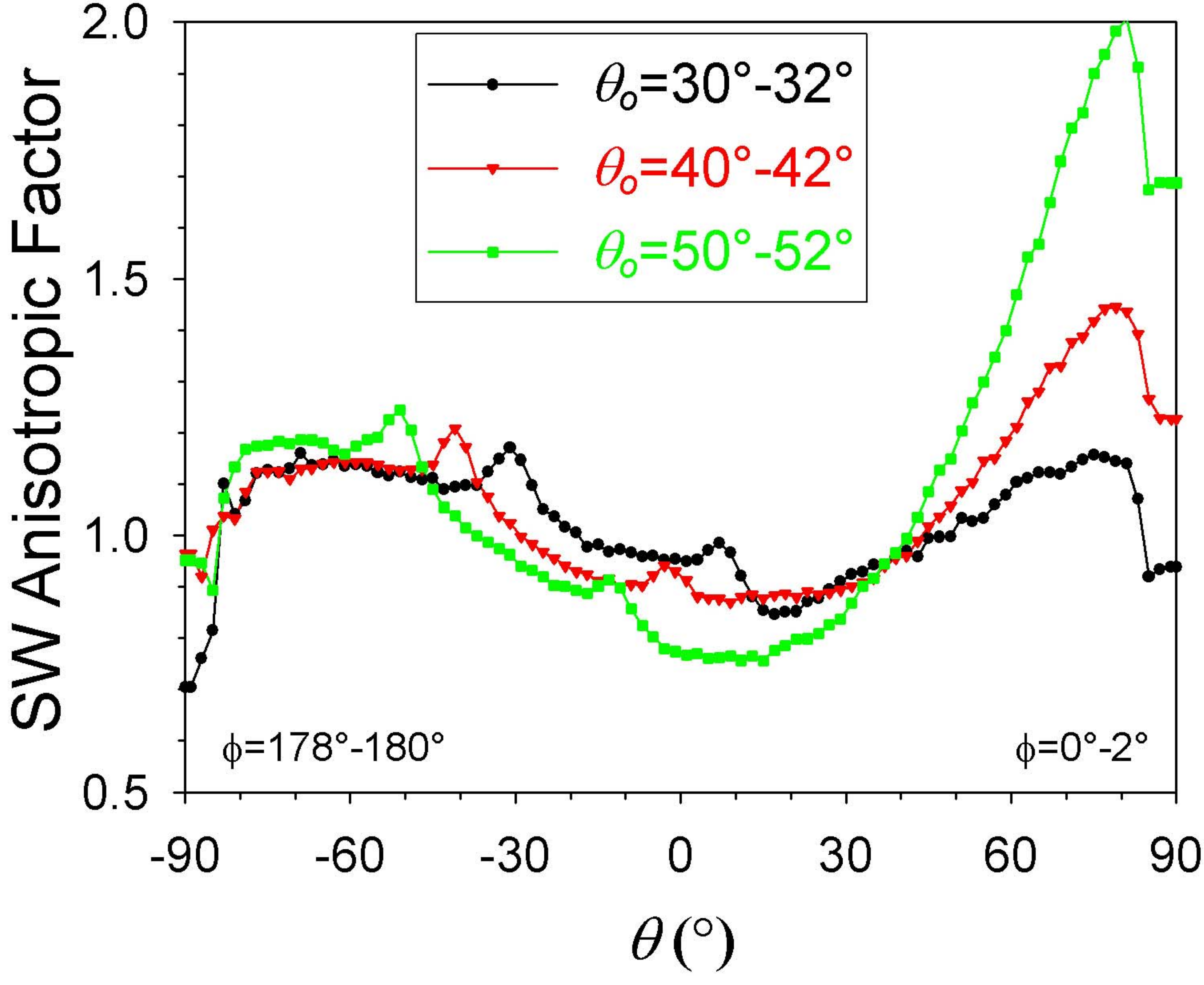
Contains all CERES-MODIS parameters on the CERES SSF product and all available MISR radiances (9 angles and 4 channels) averaged over every CERES footprint.

⇒ Can be extended to include other MISR and MODIS derived parameters

CERES/Terra Shortwave ADMs for Different Scene Types

Scene Type	Description
Clear Ocean	Function of wind speed; Correction for aerosol optical depth included.
Cloud Ocean	Function of cloud phase; Continuous function of cloud fraction and cloud optical depth (5-parameter sigmoid).
Land & Desert Clear	1° regional monthly ADMs using Analytical Function of TOA BRDF (Ahmad and Deering, 1992).
Land & Desert Cloud	Function of cloud phase; continuous function of cloud cover and cloud optical depth; uses 1°-regional clear-sky BRDFs to account for background albedo.
Permanent Snow	Cloud Fraction, Surface Brightness, cloud optical depth
Fresh Snow	Cloud Fraction, Surface Brightness, Snow Fraction, cloud optical depth
Sea-Ice	Cloud Fraction, Surface Brightness, Ice Fraction, cloud optical depth

SW Anisotropy of Liquid Water Clouds from CERES *Terra*



Uncertainty in Regional Mean SW TOA Flux: CERES ADMs vs 1D Theory

Approach

i) Construct 10°x10° latitude-longitude regional ADMs by season (e.g., DJF, JJA) from:

- **i) Measured CERES radiances**
- **ii) Radiance predicted by CERES ADMs**
- **iii) Radiance predicted by 1D theory**

ii) Apply all 3 regional ADMs to determine fluxes from the same data.

iii) Determine regional mean error in SW TOA flux.

Perform above steps separately for: liquid water clouds, ice clouds and all-sky.

1D Model Assumptions

$$I_{1D}(\theta_o,\theta,\phi) = (1-f)\, I_{CER}^{clr}(\theta_o,\theta,\phi) + f\; I_{1D}^{ovc}(\theta_o,\theta,\phi;\tau,P)$$

f = Cloud Fraction

I_{CER}^{clr} = Clear-sky radiance from CERES ADMs

I_{1D}^{ovc} = Overcast radiance from 1D theory

P = Cloud Phase (liquid or ice)

τ = Cloud Optical Depth

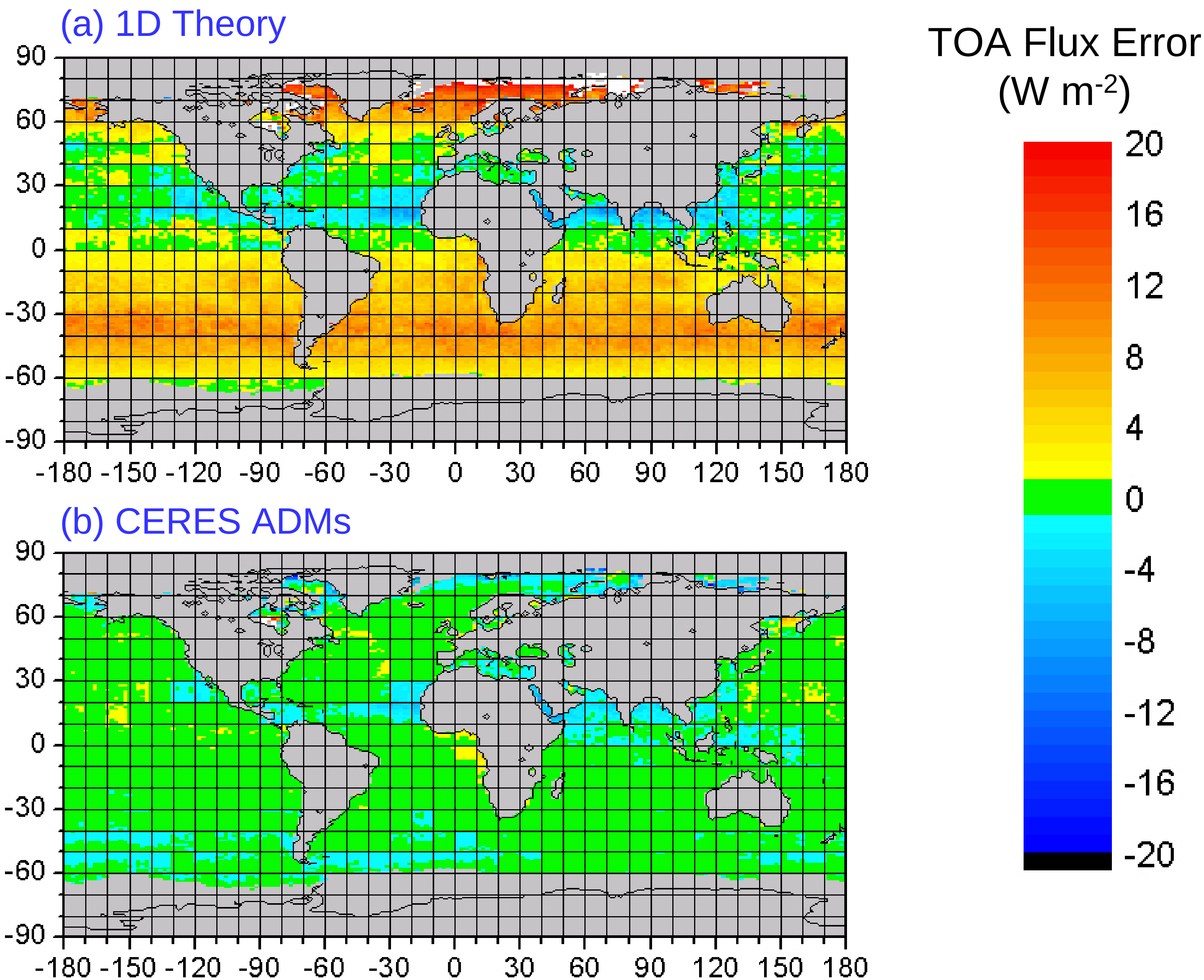
RT Model: Nakajima rstar5b

Cloud Properties:

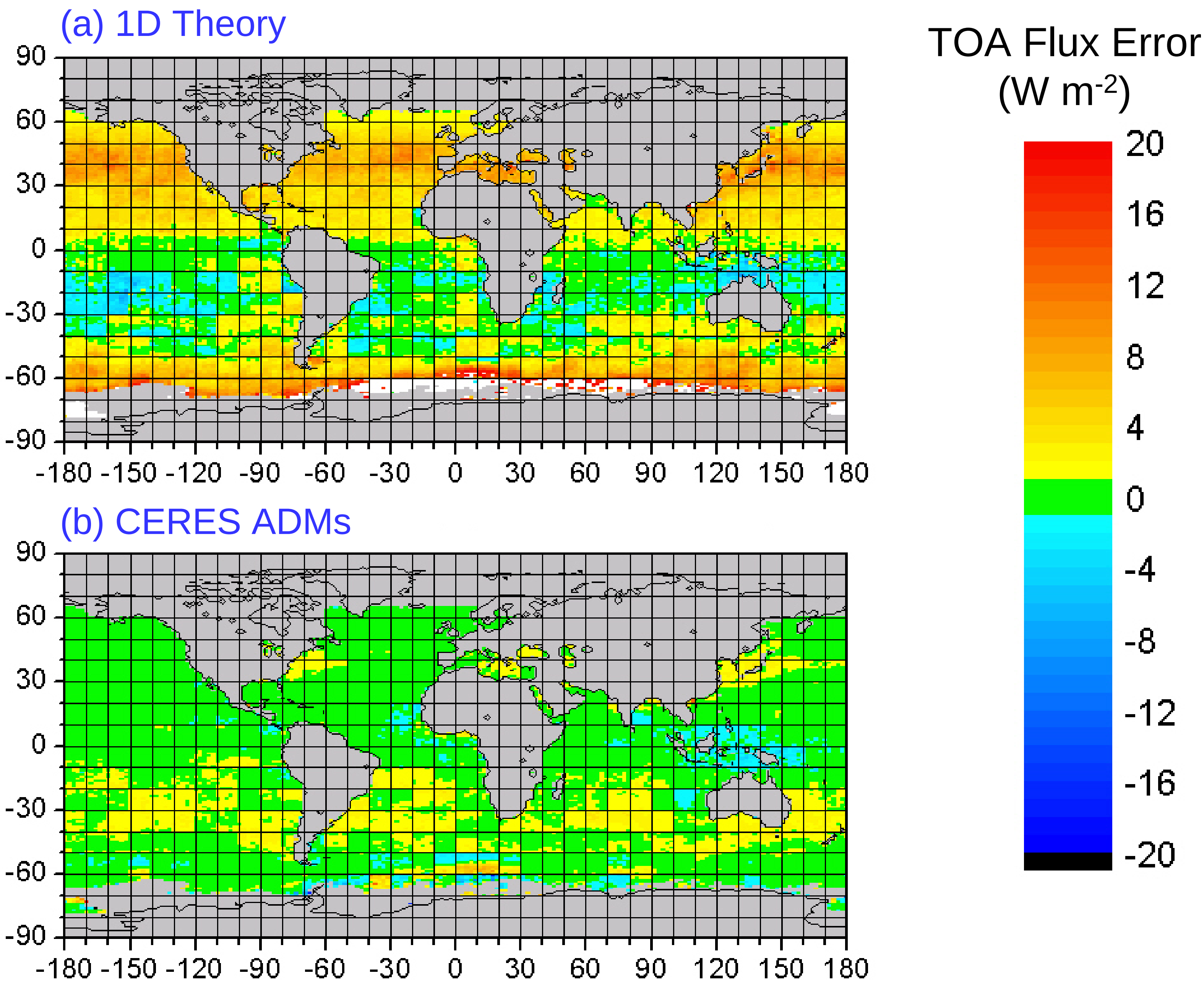
Liquid water: r_e = 10 μm; fixed cloud-top height 2 km

Ice Clouds : nonspherical; mix of crystal types (Ping Yang).

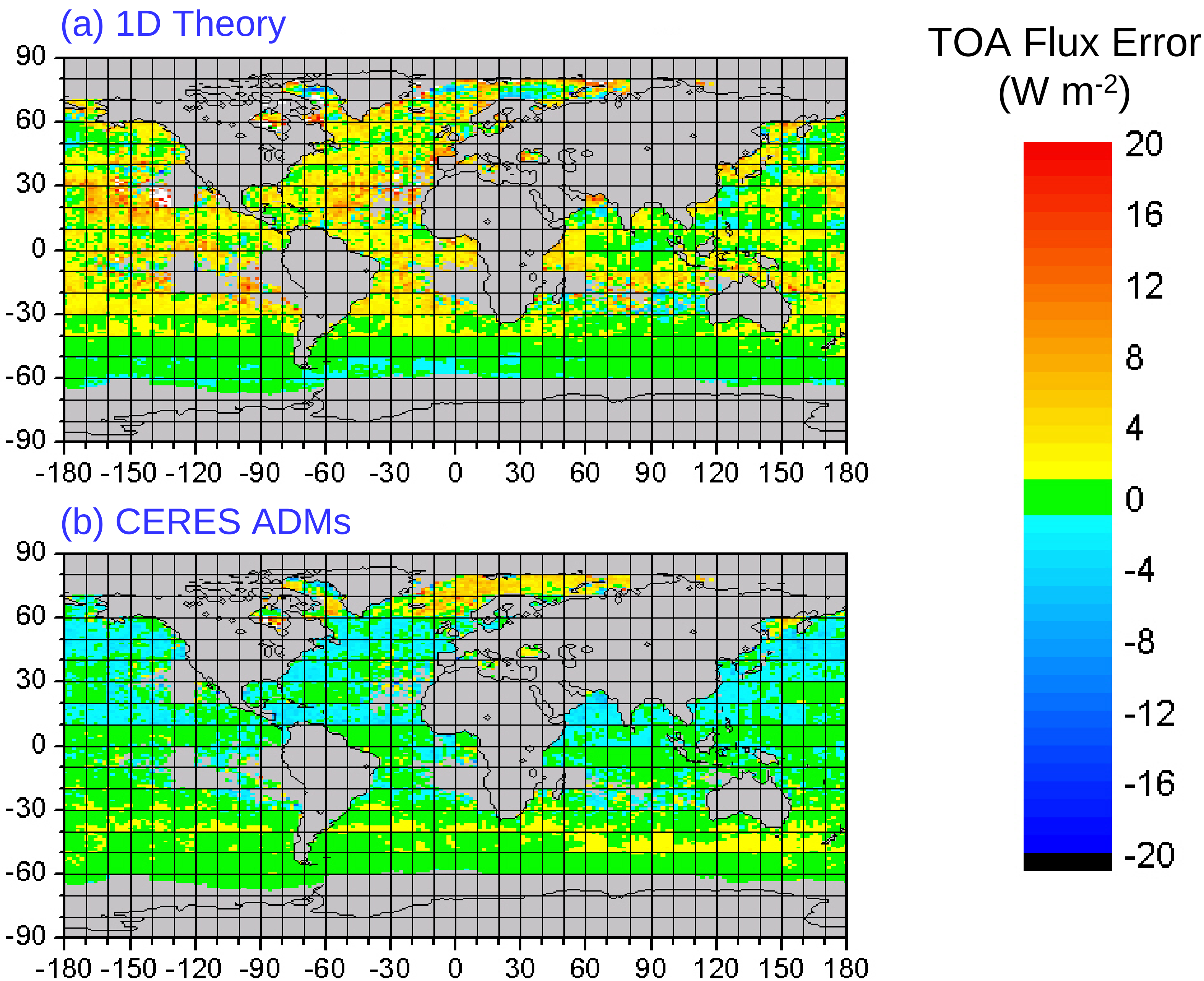
Regional Mean SW TOA Flux Error – **Liquid Water Clouds** (JJA)



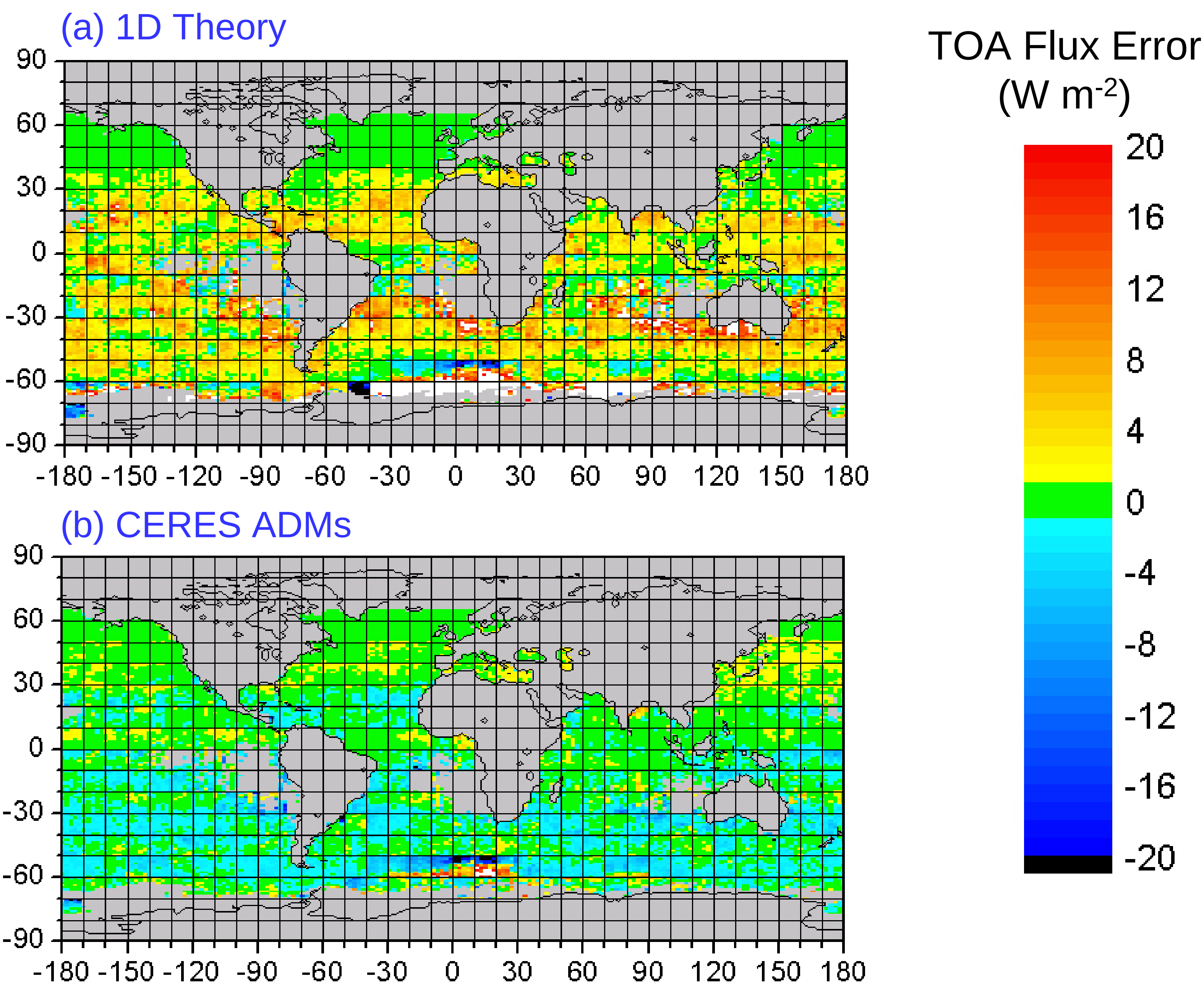
Regional Mean SW TOA Flux Error – **Liquid Water Clouds** (DJF)



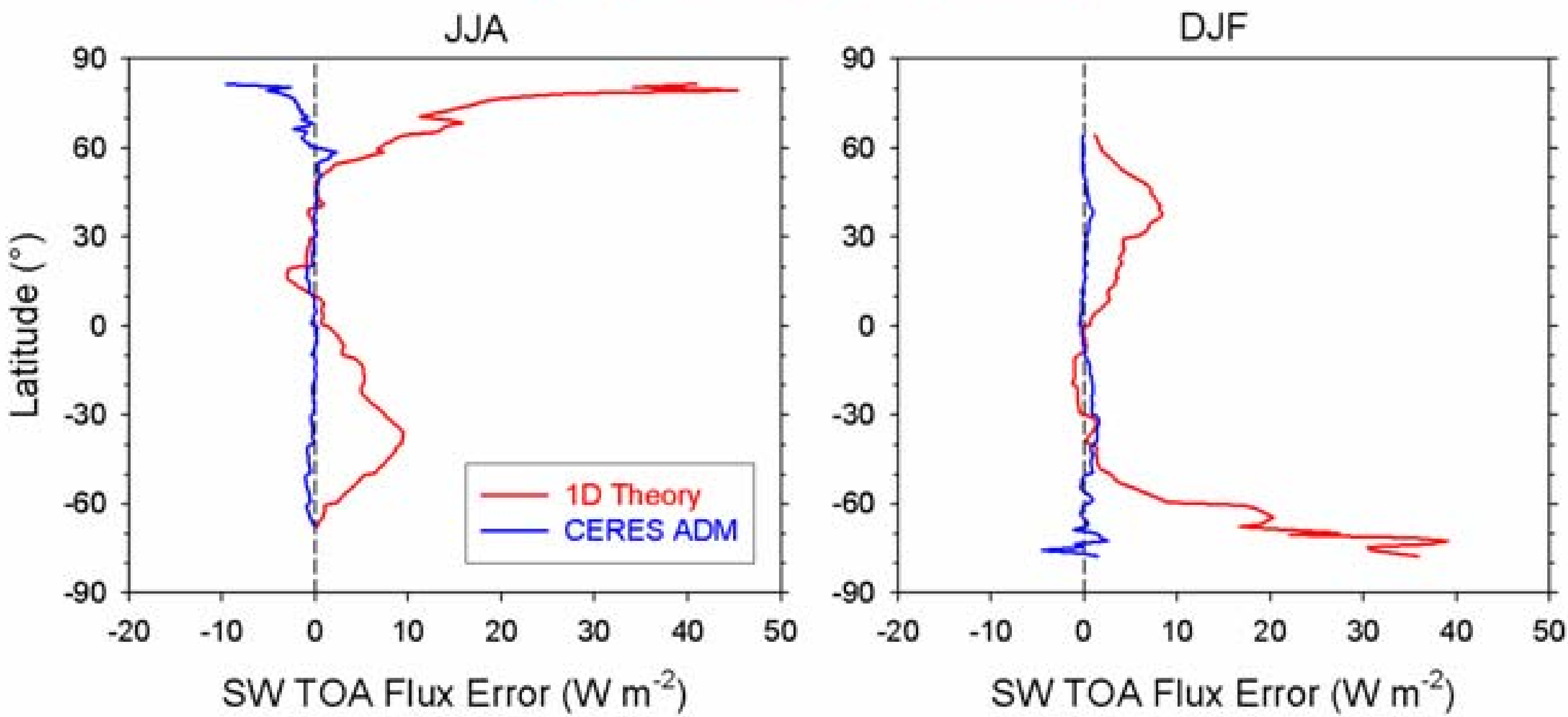
Regional Mean SW TOA Flux Error – **Ice Clouds** (JJA)



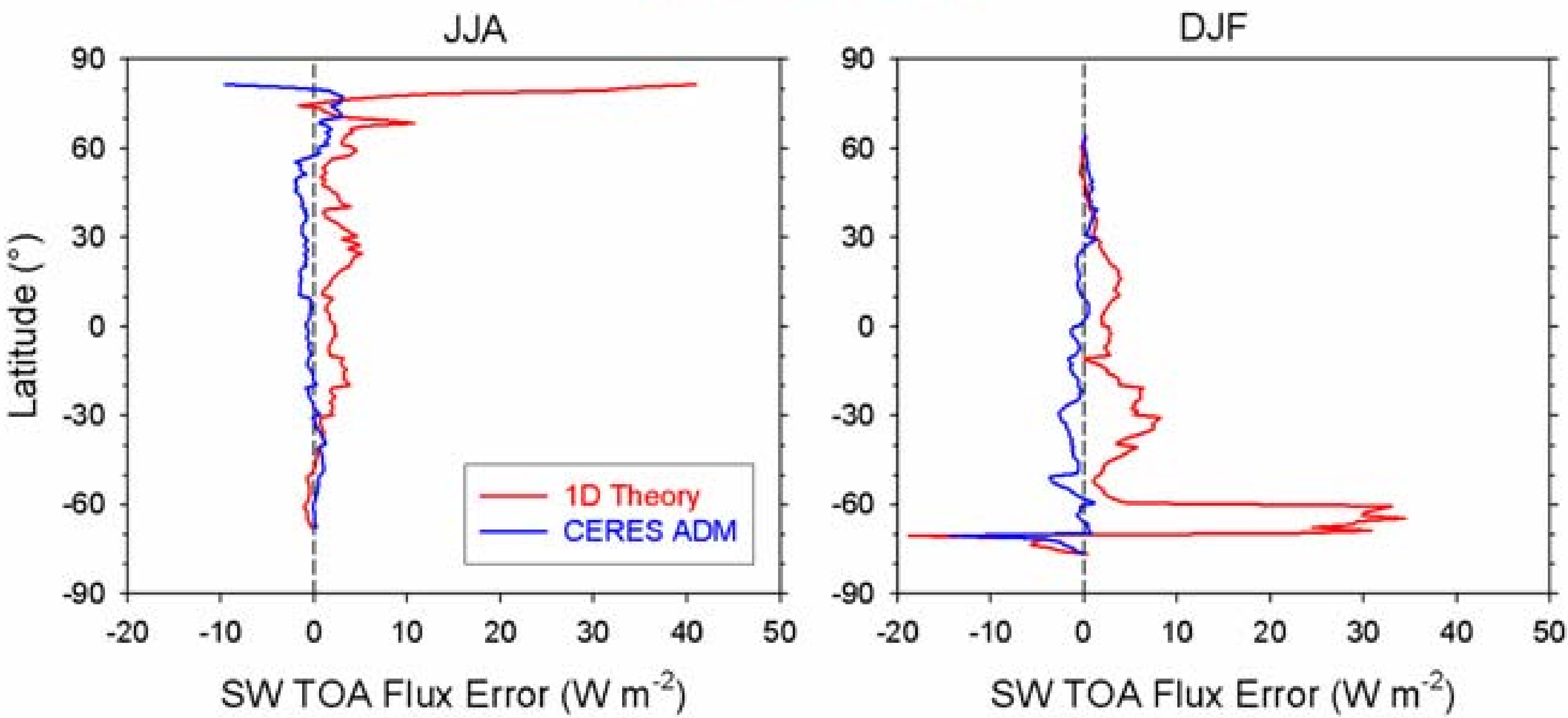
Regional Mean SW TOA Flux Error – **Ice Clouds** (DJF)



Zonal Distribution of SW TOA Flux Errors
(Liquid Water Clouds)



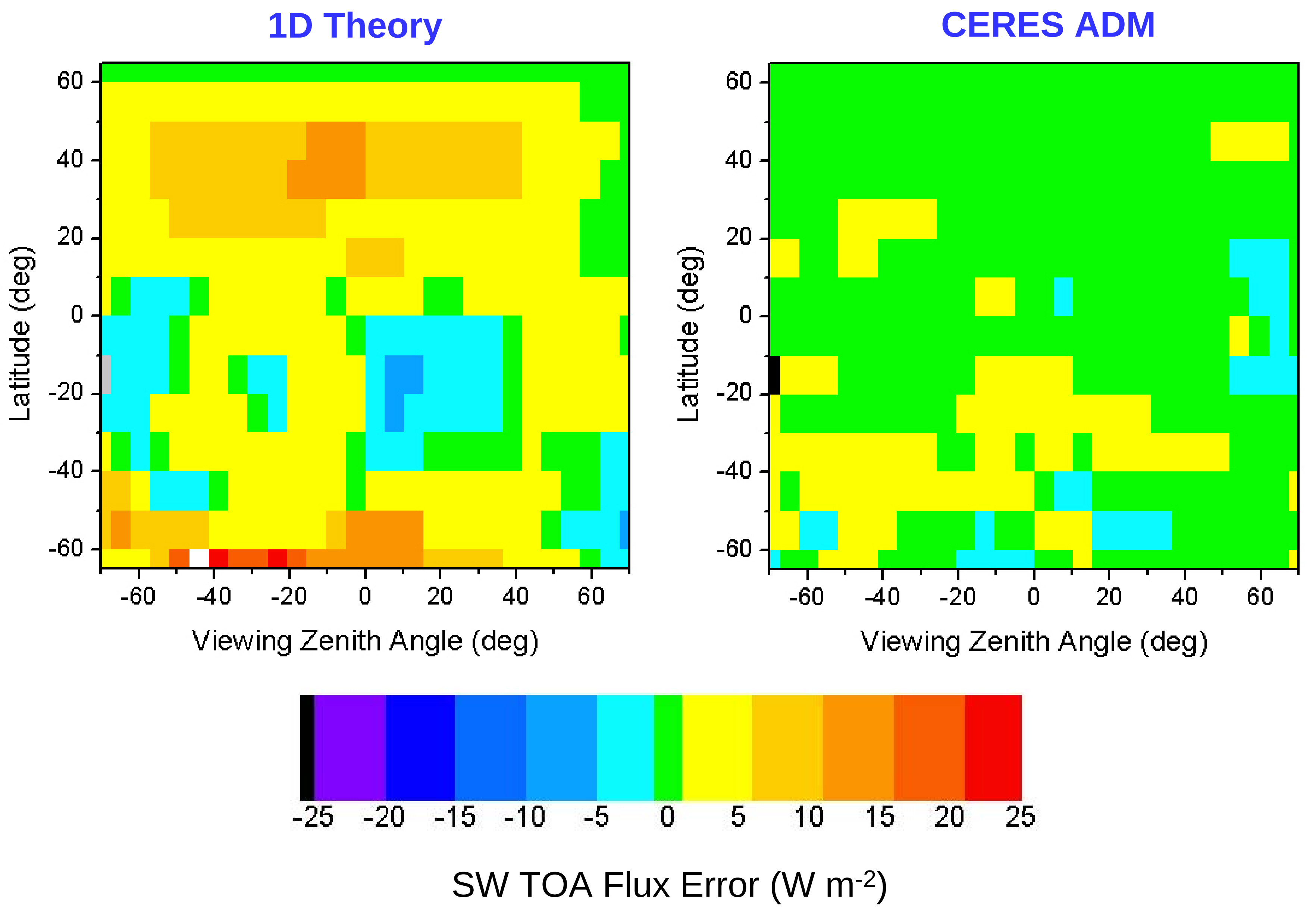
Zonal Distribution of SW TOA Flux Errors (Ice Clouds)

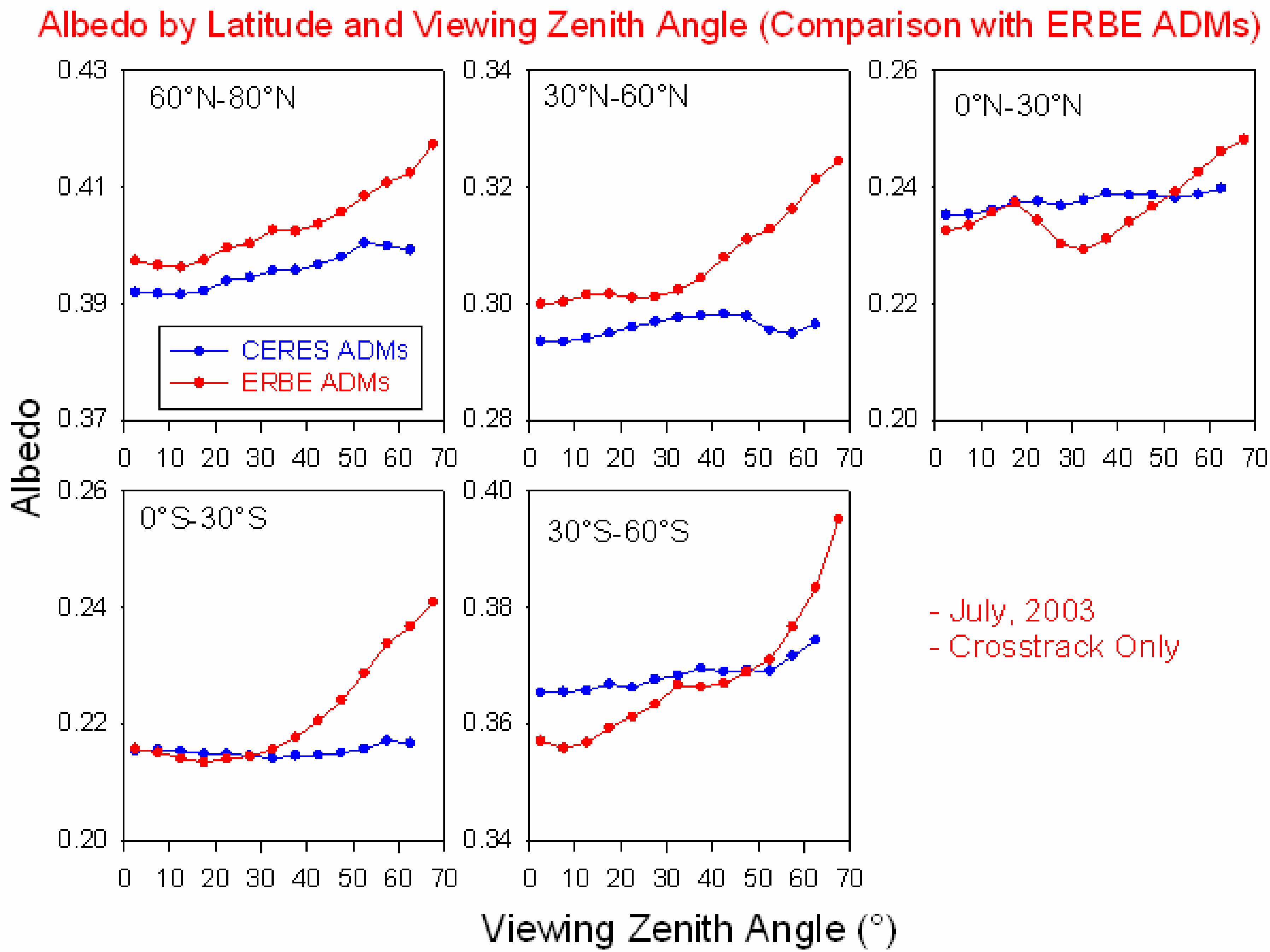


Global SW TOA Flux Error Over Ocean

	JJA		DJF	
	1D Theory ($W\ m^{-2}$)	CERES ADM ($W\ m^{-2}$)	1D Theory ($W\ m^{-2}$)	CERES ADM ($W\ m^{-2}$)
Liq H_2O Cld	3.3	-0.29	3.6	0.31
Ice Cld	1.9	-0.35	3.4	-0.53
All-Sky	2.6	-0.28	3.3	0.14

SW TOA Flux Error by Latitude and Viewing Zenith Angle (DJF 2000-2001)





Albedo by Latitude and Viewing Zenith Angle (Comparison with ERBE ADMs)
60°N-80°N
30°N-60°N
0°N-30°N
0°S-30°S
30°S-60°S
CERES ADMs
ERBE ADMs
Albedo
Viewing Zenith Angle (°)
- July, 2003
- Crosstrack Only

Summary

- Bias in SW TOA flux (oceans) from 1D ADMs is 3 W m^{-2} compared to 0.3 W m^{-2} from CERES ADMs.

- 1D SW TOA flux bias depends systematically on latitude (solar zenith angle), especially for liquid water clouds.

  => small negative bias in tropics and large positive bias (10-15 W m^{-2}) in midlatitudes.

- No noticeable viewing zenith angle dependence in TOA albedo from the new CERES ADMs.